Using the SOLO Taxonomy to Analyze Competence Progression of University Science Curricula

Claus Brabrand
IT University of Copenhagen, Denmark
brabrand@itu.dk

Bettina Dahl[1]
University of Aarhus, Denmark
bdahls@si.au.dk

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Abstract

During 2007 all Danish university curricula were reformulated to explicitly state course objectives due to the adoption of a new Danish national grading scale which stipulated that grades were to be given based on how well students meet explicit course objectives. The Faculties of Science at University of Aarhus and University of Southern Denmark interpreted "course objectives" as "intended learning outcomes" (ILO) and systematically formulated all such as competencies using the SOLO Taxonomy that operates with five numbered progressive levels of competencies. We investigate how the formulation of ILOs using the SOLO Taxonomy gives information about competence progression, educational traditions, and the nature of various science subjects. We use all the course curricula (in total 632) from the two faculties to analyze and compare undergraduate and graduate courses within each department, and different departments with each other.[2]

Background

The backwash effect of examinations is a well-known phenomenon at all levels of education and it is seen in typical student questions such as: "Is this going to be a question on the examination paper?" A related question to teachers is: "What is the use of this?" Sometimes teachers have good answers, other times they say something along the line that it will be useful later. But what is it that the students are supposed to learn which will be useful later? Course descriptions are often lists of topic areas the students are to "learn about", but is "to learn (to do)" the same as "to learn about"? Take for instance cooking. To "learn to cook" is rather different than to "learn about cooking". University teachers are often the same persons who designed the courses but what tools can they use to describe what the students are supposed to "learn (to do)" and not just "learn about"? We will return to this shortly.

During the spring of 2007, the University of Aarhus (AU) in Denmark implemented the new national grading scale that is to be used from now on at all educational levels in Denmark. The rationale for the new grading scale was primarily that the old scale was very different from other grading scales in the world and it was therefore impossible to make a unique translation to and from these other grading scales which was particularly a problem for comparability and mobility between Denmark and other European Union countries. Furthermore, the existing scale suffered from inflation and in-homogeneous use – i.e. it was used differently in various topics. For instance ‘Danish’ tended to use only the middle grades whereas ‘Mathematics’ used the whole scale – but not so much the middle grades (Danish Ministry of Education, 2004). The Danish Parliament therefore approved the “7 Steps Scale” in March 2006 (see Appendix A). The 7 Steps Scale adhered to the European Bologna Process that *inter alia* focuses on a shift to outcome-based education and student mobility, hence grades should now be given based on the *degree of fulfilment* of explicitly stated course objectives (Dahl, 2008; Dahl et al., 2009). Therefore, all university curricula had to be rewritten to include explicit course objectives whereas before the curricula were described in terms of course content only.

At The Faculty of Science at the University of Aarhus (NAT/AU) “course objectives” were interpreted to mean “intended learning outcomes” (ILOs). At NAT/AU, where the two authors at that time both worked, all curricula were therefore rewritten to include ILOs formulated as competencies. The two authors were part of a five-people Working Group chaired by Brabrand that gave a mandatory course to all the academic staff[3] at NAT/AU primarily explicating how to formulate the ILOs as competencies using the SOLO Taxonomy, which operates with five numbered levels of competencies (Biggs & Collis, 1982; Biggs, 2003; Biggs & Tang, 2007). Secondarily, we emphasized the importance of alignment between ILOs, forms of teaching, and forms of examination. Part of the purpose of the course was to develop a common language among the academic staff to express and understand the various SOLO levels, competencies, and ILOs. It was also necessary in order to ensure comparability and alikeness in the standardisation of curricula. The Working Group gave recommendations on how to transform the curricula and gave several examples for illustration. Next, a key person at each of the departments at NAT/AU was obliged to create five “good examples” of course descriptions which were subsequently revised and approved in concert with the Working Group. Based on the “good examples” the rest of the curricula were created under supervision of the key persons and then finally reviewed and approved by the Study Board, whose chairman was also a member of the Working Group. We compare NAT/AU with the Faculty of Science at the University of Southern Denmark (NAT/SDU) that chose a very similar approach and also described ILOs using the SOLO Taxonomy and where Brabrand was a consultant and course leader. Many hands have therefore been involved in designing the new course descriptions, but it is not the aim of this analysis to find out which hand did exactly what. Instead we investigate if the end product of such a process namely the quantification of ILOs, can be useful to analyse for progression of competencies and what it can tell us about different educational traditions and the nature of the various subjects. The total data set consists of 632 curricula and it is the first time in Denmark that university curricula systematically on a larger scale have been transformed into formulation of ILOs and therefore gives a unique opportunity for scientific inquiry.

Research questions / contributions

This paper centres on how, and if, the use of the SOLO Taxonomy makes it possible to research and provide answers to the following three focus areas:

Competence progression:

1. Is there progression in competencies in the curricula from undergraduate level to graduate level?

Educational traditions and nature of subjects:

2. Are there differences between the departments at the same Faculty of Science?

Stability of the analysis across universities:

3. Are there differences between sister-departments at the two Faculties of Science?

Outline of the paper

First, the SOLO Taxonomy and why it was chosen is described. Then, we describe the method of analysis including the assumptions behind the study. After that we discuss the results and conclude on the three focus areas.

Taxonomies for understanding "understanding"

The purpose of university teaching is *inter alia* that students should learn something; i.e., they should attain some level of understanding and skills. However, the term 'understanding' is used for many different things such as one student's capacity to *name* main concepts involved in topic X and another student's *critical comparison* of practical implications of theoretic models of topic X. These two uses of 'understanding' are different and embody both surface and deep understanding, respectively. According to Wittgenstein, words get their meaning from their use: "Nur in der Praxis einer Sprache kann ein Wort Bedeutung haben" (Wittgenstein, 1991, p. 344), but the usage of 'understanding' is ambiguous, hence its meaning is not clear. In Sausurre's (1997, pp. 12-13) terminology, one could say that the term 'understanding' is a double entity constituted by one distinct succession of syllables (*syllables*), but multiple meanings (*signification*) linked to the syllables. Some clarity is therefore needed when one for instance explains the kind of understanding of topic X that is intended by the teacher and that will be tested at an examination. Skemp (1987, pp. 152-163) defined two types of understanding. 'Instrumental understanding' is "rules without reasons" for instance that you 'understand' that to divide a fraction by a fraction "you turn it upside down and multiply". 'Relational understanding' occurs when one has built up a conceptual structure (schema) of topic X and therefore both know *what* to do and *why* when one solves a problem within that topic. However, Skemp's distinction does not formulate a gradual development or levels of understanding. There are several taxonomies describing various levels of understanding. Gall (1970) presented an overview of eight of these of which Bloom's is probably the most well known. These have been developed *inter alia* to classify questions "based on the type of cognitive process required to answer the question" (Gall, 1970, p. 708). Gall furthermore stated: "I have organised the categories to show similarities between the systems. It appears that Bloom's *Taxonomy* best represents the commonalities that exist among the systems" (Gall, 1970, p. 710). Lewis (2007) gave a rather similar overview of five taxonomies. Below is Gall's presentation of eight taxonomies:

Author	Classification				
	Recall	Analytic thinking	Creative Thinking	Evaluative thinking	Other
Adams (1964)	Memory	Ratiocinative (logical reasoning)	—	Evaluative	Associative, clarifying, neutral
Aschner (1961)	Remembering	Reasoning	Creative thinking	Evaluating	—
Bloom (1956)*	Knowledge	Analysis	Synthesis	Evaluation	Comprehension, application
Carner (1963)	Concrete	Abstract	Creative	—	—
Clements (1964)	Past experience, process recall	—	Planning	Product judgment	Present experience, rule, opening, identification, suggestion, order, acceptance
Guszak (1967)	Recognition, recall	Explanation	Conjecture	Evaluation	Translation

Pate & Bremer (1967)	Simple recall of one item, recall-choice of multiple items	Principle involved, concept analysis	Divergence	—	Determination of skills abilities (demonstrate), skills demonstration (verbal), example-singular, examples-multiple
Schreiber (1967)	Recall of facts, arranging facts in sequential order	Making comparisons, identifying supporting facts, drawing conclusions	Speculating on outcomes	Identifying main part & important parts, stating moral judgment, stating judgment based on personal experience, evaluating quality of source material, evaluating adequacy of data	Describing situations, defining & clarifying information, using globes, using maps, uncovering information & raising questions for study

*) In the complete system, each category is divided into sub-categories.

Figure 1: Overview of eight taxonomies (Gall, 1970, p. 709). See Gall's references in Appendix B.

These taxonomies have been further developed but the basic ideas are still the same and particularly Bloom's Taxonomy is still very widely used. However, they were not developed specifically with university teaching in mind and furthermore Bloom did not make his taxonomy with the purpose of formulating ILOs but to be able to select representative tasks for an examination (Biggs & Collis, 1982, p. 13). Below we therefore present a taxonomy for understanding "understanding" particularly aimed at assessing university students' competencies. Following the discussion from above, this taxonomy distinguishes between "learn (to do)" and "learn about". Lists of "learn about" are *content* statements using *nouns* listing the concepts and areas of knowledge that the students will encounter during the course. But this is not the same as what they "learn (to do)". Curricula writers need to ask themselves what they want the students to get out of meeting these areas of knowledge; i.e., what do they want the students to learn to *do*? When assessing a student, we cannot actually measure the student's knowledge "inside the brain". What we can do, however, is to have a student *do* something, and then measure the product and/or the process. Therefore, it is important to focus on what the student *does* and on what the students are supposed to "learn (to do)", i.e. what *competencies* the students are expected to have by the end of the course. As generally advocated in Outcomes-Based Education (OBE); in particular, in Constructive Alignment (Biggs, 2003), we therefore focused on having course descriptions with ILOs formulated using *verbs* stating what the students should be able to *do* by the end of the course. Having these things made explicit furthermore makes it easier to explain to the students what they are supposed to get out of a course.

The SOLO Taxonomy

The SOLO Taxonomy is based on the study of *outcomes* of academic teaching. SOLO is short for "*Structure of the Observed Learning Outcome*" and the taxonomy names and distinguishes five different levels according to the cognitive processes required to obtain them: "SOLO describes a hierarchy where each partial construction [level] becomes a foundation on which further learning is built" (Biggs, 2003, p. 41). SOLO can be used to define ILOs, forms of teaching that support them, and forms of assessment that evaluate to what extent the ILOs were achieved. It is developed aiming at research-based university teaching as the research activities behind it ultimately converge on real research (i.e. on the production of new knowledge) at its fifth and highest level. The five levels are as follows, in increasing order of structural complexity (Biggs & Collis, 1982, pp. 17-31; Biggs, 2003, pp. 34-53; Biggs & Tang, 2007, pp. 76-80):

SOLO 1: "The Pre-Structural Level"
Here the student does not have any kind of understanding but uses irrelevant information and/or misses the point altogether. Scattered pieces of information may have been acquired, but they are unorganized, unstructured, and essentially void of actual content or relation to a topic or problem.

SOLO 2: "The Uni-Structural Level"
The student can deal with one single aspect and make obvious connections. The student can use terminology, recite (remember things), perform simple instructions/algorithms, paraphrase, identify, name, count, etc.

SOLO 3: "The Multi-Structural Level"
At this level the student can deal with several aspects but these are considered independently and not in connection. Metaphorically speaking; the student sees the many trees, but not the forest. He is able to enumerate, describe, classify, combine, apply methods, structure, execute procedures, etc.

SOLO 4: "The Relational Level"
At level four, the student may understand relations between several aspects and how they might fit together to form a whole. The understanding forms a structure and now he does see how the many trees form a forest. A student may thus have the competence to compare, relate, analyze, apply theory, explain in terms of cause and effect, etc.

SOLO 5: "The Extended Abstract Level"
At this level, which is the highest, a student may generalize structure beyond what was given, may perceive structure from many different perspectives, and transfer ideas to new areas. He may have the competence to generalize, hypothesize, criticize, theorize, etc.

We define *competence progression* as moving up the SOLO levels; i.e. SOLO-progression. Surface learning (which has similarities to instrumental understanding) implies that the student is confined to action at the lower SOLO levels (2-3); whereas deep learning (which has similarities to relational understanding) implies that the student can act at any SOLO level (2-5), including the higher levels (4-5). As we move up the SOLO hierarchy, we first see *quantitative* improvements as the student becomes able to deal with first a single aspect (from 1-2) and then more aspects (from 2-3). Later we see *qualitative* improvements (from 3-4) as the details integrate to form a structure; and (from 4-5) as the structure is generalized and the student can deal with information that was not given. For these reasons, the levels 2 and 3 are sometimes referred to as *quantitative* levels; levels 4 and 5 as the *qualitative*. The figure below lists prototypical competencies from the SOLO Taxonomy:

- Quantitative -		- Qualitative -	
SOLO 2 *"uni-structural":*	SOLO 3 *"multi-structural":*	SOLO 4 *"relational":*	SOLO 5 *"extended abstract":*
- paraphrase - define - identify - count - name	- combine - classify - structure - describe - enumerate	- analyze - compare - contrast - integrate - relate	- theorize - generalize - hypothesize - predict - judge

- recite - follow (simple) instructions - …	- list - do algorithm - apply method - …	- explain causes - apply theory (to its domain) - …	- reflect - transfer theory (to new domain) - …

Figure 2: Examples of verbs within SOLO 2-5 based on Biggs (2003, p. 48).

Analysis Method

Below we will describe our calculation methods and explicate the assumptions on which the analysis rests.

Calculation methods

Each course has a number of ILOs and each ILO has a number of competencies (in many cases one, but sometimes more). For each course we assume that all ILOs weigh the same and within each ILO we assume each competence weighs the same. This is an approximation, which we will address further below. The verbs used to describe the competencies are then quantified via the SOLO Taxonomy. As an example, let us consider the ILOs from the course description of the "Genetics 101" from the Department of Biology, AU:

At the end of the course, the student is expected to be able to…:
- **calculate** (SOLO 2) recombination frequencies, segregation ratios, inbreeding coefficients, Hardy-Weinberg frequencies, evolutionary equilibria, heritabilities etc. - **explain** (SOLO 4) and **apply** (SOLO 3) linkage analysis, including mapping of genes on chromosomes - **describe** (SOLO 3) and **analyse** (SOLO 4) simple patterns of inheritance (i.e. through analysis of pedigrees) - **describe** (SOLO 3) and **explain** (SOLO 4) the concepts of genetic variation, mutation, inbreeding, genetic drift, and natural selection - **describe** (SOLO 3) and **explain** (SOLO 4) evolutionary processes - **analyse** (SOLO 4) the inheritance at several genes simultaneously - **explain** (SOLO 4) how inbreeding and population mixture influence genetic structure.

Figure 3: An example of ILOs from a course description (here: "Genetics 101", Biology).

As can be seen, this course has seven ILOs; three of which have one competence, and four of which have two competencies. The individual competencies are highlighted in boldface, with the SOLO level given in parentheses. "Genetics 101" does not feature any SOLO 5 competencies (presumably because it is a first year introductory course). We may then calculate a *"SOLO average"*:

$$[\ 2.0 + (4+3)/2 + (3+4)/2 + (3+4)/2 + (3+4)/2 + 4.0 + 4.0\ ]\ /\ 7 = \underline{3.43}$$

This calculation consists of, in square brackets, a calculation of the averages of each of the seven ILOs seen in Figure 3 above. The numbers refer to the SOLO level of the various verbs. All the averages for each the seven ILOs are added together, then divided by 7 (the number of ILOs) to find "the average of the ILO averages". Hence, the "SOLO average". This is a kind of double weight average. Here we assume that the numbers can be used as in a ratio scale, and that we can therefore use the full range of mathematical operations on them. We will discuss this further in the "Assumption" section below. Such an average permits us to compare courses according to their average SOLO levels. Courses may also be compared according to their *distribution* of SOLO levels which for the ILOs of "Genetics 101" yield (again using double weight averaging):

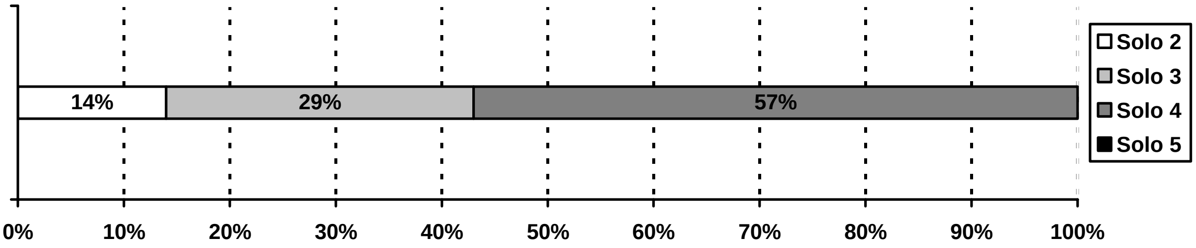


Figure 4: Relative distribution of SOLO levels for the competencies of "Genetics 101".

Something worth noting is that for instance the first ILO lists several topic areas (i.e., nouns) to its competence. One might argue that these topics may just as well have been written out as individual ILOs, each with its own SOLO 2 verb (here, "to calculate"). This example course would then have had a lower SOLO average as proportionately more competencies would have been at level 2. We assume, however, that since the teacher in charge of writing the curricula have chosen to write it specifically in this way, it is because the specific competence 'to calculate' has a proportionate weight in the course compared to the rest of the ILOs. This is a reasonable claim since the course descriptions serve to clearly communicate the teacher's intention with the course to the administration, fellow teachers, external examiners, and to the students. Furthermore the curricula in each department were rewritten based on the five standard "good examples" which also exhibited this dilemma and which were approved of by both the Working Group and Study Board.

Syntactically, most ILOs were structured using regular transitive verbs with a sentence structure along the lines of the following (here rephrased in direct speech, with the structure in italics below):

"[students]	**explain**	evolutionary processes"
<subject>	***<verb>***	*<direct object>*

However, some ILOs are syntactically structured around so-called *di-transitive verbs*; e.g.:

"[students]	**apply**	Schrödinger equation	to	**analyze** quantum mechanic problems"
<subject>	***<1st verb>***	*<direct object>*	*<preposition>*	*<indirect object (with **2nd verb**)>*

In this example, 'apply' is the di-transitive verb where there is a second verb embedded in the indirect object. In such cases, we count both competencies (here, 'apply (method)' at SOLO 3 and 'analyze' at SOLO 4) on an equal footing, in this case yielding an average of (3+4)/2 = 3.5. Such ditransitive verbs occur in 132 out of the 3,510 ILOs (~ 3.7%). Of course, multiple verbs in an ILO may also occur through regular conjunction (see Figure 3 above) in which case they too are averaged.

SOLO Classification

We collected all the curricula from the two science faculties from one entire academic year. This gave us a data set consisting of 734 courses and a total of 5,608 competencies (all available online; see Appendix C). We excluded Statistics, Nano Technology, and Sport Science from the analysis because these subjects were housed in sub-Department entities with fewer courses for which a large variance could compromise our calculation of averages. We then extracted all competencies (verbs) from all ILOs from our remaining data set of 632 courses which resulted in a total of 4,921 competencies, covered by 281 distinct verbs. Next, we excluded three categories of verbs which are not captured and addressed by the SOLO Taxonomy: *non-operational competencies* (e.g., ‘to understand’, ‘to know’, ‘to master’), *communicational activities* (e.g., ‘to present’, ‘to write’, ‘to read’), and *professional activities* (e.g., ‘to work’, ‘to participate’, ‘to be involved in’). These verbs were subsequently ignored in the calculation of averages and SOLO distributions, which left us with 207 verbs to classify according to the SOLO Taxonomy (used in 4,494 competencies). For each of these verbs, we carefully looked at the contexts in which it occurred to determine its appropriate SOLO-level. We finally compiled a table featuring all competencies according to their SOLO-levels.

Classification stability

To make sure we had a solid and stable classification for our analysis, we went through a number of control measures. First, we consulted many of the teachers who had originally authored the ILOs on how certain verbs should be classified. Then, we approached three educational research colleagues from the Faculty of Health Sciences at University of Aarhus (SUN/AU) that were in charge of implementing ILOs in course curricula at their faculty, also using the SOLO Taxonomy. They gave us feedback on our classification which in some cases led us to revise our classification. Finally, we consulted Catherine Tang and John Biggs who provided us with feedback which led us to further revise our classification. In the end, we did have a few disagreements which, in our opinion, mainly fall in two categories: *science specifics* and *linguistic issues* each of which is elaborated below. But first, we present the product of this iterative process; the classification which lists all the competencies occurring more than ten times in ILOs at both universities when combined, along with their occurrence count in parentheses (which is an interesting “by-product” of our analysis in itself):

- Quantitative -				- Qualitative -			
SOLO 2 *”uni-structural”:*		SOLO 3 *”multi-structural”:*		SOLO 4 *”relational”:*		SOLO 5 *”extended abstract”:*	
- identify	(168)	- describe	(677)	- explain	(382)	- discuss	(212)
- calculate	(80)	- account for	(593)	- analyze	(281)	- assess	(125)
- reproduce	(64)	- apply method	(485)	- compare	(103)	- evaluate	(58)
- arrange	(56)	- execute	(154)	- argue	(75)	- interpret**	(51)
- decide	(32)	- formulate	(85)	- relate	(70)	- reflect	(39)
- define	(25)	- use method	(75)	- implement	(55)	- perspectivate	(37)
- recognize	(25)	- solve	(68)	- plan	(44)	- predict	(28)
- find	(20)	- conduct	(61)	- summarize	(35)	- criticize	(19)
- note	(17)	- prove	(57)	- construct	(31)	- judge	(19)
- seek	(16)	- classify	(36)	- design	(31)	- reason	(10)
- choose	(16)	- complete	(34)	- interpret*	(21)		
- test program	(13)	- combine	(25)	- structure	(18)		
- sketch	(10)	- list	(19)	- conclude	(17)		
- pick	(10)	- process	(16)	- substantiate	(17)		
		- report	(16)	- exemplify	(14)		
		- illustrate	(13)	- derive	(11)		
		- express	(12)	- adapt	(10)		
		- characterize	(11)				

Figure 5: SOLO Classification of verbs occurring at least 10 times in the data set. (Explanation of the asterisks is given below.)

Science specifics

During interaction with our colleagues from SUN/AU, we learned that verbs are used a little differently at different faculties although we agreed on most. At NAT/AU, for instance, ‘to prove’ was used in the sense of “reproducing” mathematical proofs “on the blackboard” which are known from textbooks and available in advance – essentially carrying out a sequence of known steps (hence SOLO 3). At SUN/AU, it was mostly used where students had to “construct” a proof themselves from various known pieces and thus establish a conclusion in connection with a problem (hence SOLO 4).

Even within science, one might argue that for instance “to compare” (SOLO 4) is not equally easy/difficult in all topics. However, we assume that within each topic there is an internally consistent progression so that, for instance, one cannot ‘compare’ within topic X without having many of the competencies at the SOLO 2-3 within topic X, for instance, ‘classify’, ‘describe’, ‘list’ (SOLO 3) and ‘define’, ‘identify’, ‘find’ (SOLO 2). This is exactly why it is interesting to both describe progression within each department but also to say something about the nature of the various subjects and their educational traditions. However, a goal of this paper is *SOLO* progression which is not necessarily always the same as progression in difficulty.

Linguistic issues

All ILOs were originally authored in Danish and have thus been translated to English in this paper. In a very few cases, we had different Danish verbs mapped to the same English verb (a well-known phenomenon in translation). For instance, the Danish verbs ‘bruge’ and ‘benytte’ both translate to ‘use’ and thus combined into one verb (hence adding the two occurrence counts). In a single case however, we did have an interesting linguistic side-effect that posed some problems initially. The Danish verbs ‘fortolke’ and ‘tolke’ both translate to English as ‘interpret’. The latter ‘tolke’ means more the SOLO 4 level ability to (just) “transfer/translate” something from one context to another, while the former ‘fortolke’ additionally incorporates a value judgement, which ‘tolke’ does not, much as with ‘evaluate’ and ‘assess’ rendering it at SOLO 5. This discrepancy between the two instances of ‘interpret’ was confirmed (in fact unanimously) by our Danish-native SOLO-knowledgeable colleagues when consulted about the matter. Thus, we have kept the two verbs apart in the analysis; hence the two different occurrences of ‘interpret’ in Figure 5 (asterisks). In only a few cases, did we find *ambiguous verbs* with different meanings in different contexts. One such example is the Danish verb ‘fremstille’ which means ‘to manufacture’ or ‘to produce’. This was in some cases used in the sense of following a stepwise recipe or procedure (SOLO 3) as in “to manufacture a chemical substance”; and, in other cases “to produce a written report” as a kind of *professional activity* which we thus excluded from the analysis as mentioned above.

Assumptions

The calculation explained above has been conducted for each of 632 courses at the science faculties at AU and SDU. The calculation method, however, builds on a number of assumptions, which we have made explicit and address in the following:

1. The SOLO classification is appropriate;
2. SOLO is an appropriate measure for progression (at all);
3. Progression manifests itself as increases in competencies (i.e., in “verbs”, not “nouns”);
4. The ILOs of each course and each competence within an ILO weigh the same;
5. The numeric step between adjacent SOLO-levels is the same (i.e., 2-3 vs. 3-4 vs. 4-5);
6. *Formulated* outcomes (which we analyze directly) have an impact on the *realized* outcomes (which we ultimately would like to reason about, indirectly).

1. Appropriate classification

Obviously, the analysis rests on the appropriateness of the SOLO classification. As explained above, five independent educational researchers experienced with the SOLO Taxonomy have gone through the classification with only minor differences in opinion regarding the end product (Figure 5). It is worth pointing out that it will take a substantial number of "reclassifications" to significantly affect the outcome of the analysis, given the large size of our data.

2. SOLO appropriate progression measure

We would argue that the SOLO Taxonomy is an appropriate measure of competence progression; in particular, its hierarchical and linear structure makes it a good candidate for an analysis such as the one we propose. Ultimately, we base ourselves on the validity of the research by Collis and Biggs, which lead them to conceive the SOLO Taxonomy (Biggs & Collis, 1982; Biggs, 2003; Biggs & Tang, 2007) as a measure for (increasing) student competence.

3. Progression in verbs

We are mostly investigating *competence* progression which we hope to analyze and assess via the SOLO Taxonomy. It is beyond the reach of the SOLO Taxonomy and scope of this paper to investigate progression in the content part of ILOs or progression in the level of abstraction. However, from an operational perspective (i.e., what students learn to *do*), we expect courses to exhibit progression in competencies.

4. Equal weight

As previously explained, the calculation method in our analysis assumes that each of the competencies within an ILO and that each of the ILOs weigh the same. This is of course an approximation, but we do not expect it to significantly deviate from the "true average" we in theory could have gotten by asking all teachers to annotate all ILOs with a percentage weight. However, even if each ILO does not in practical teaching weigh exactly the same, within each department the ILO would vary the same way, since each course has been approved by the same key person, who had initially provided the academic staff with the "good examples" to follow. Hence, we are still able to say something about the SOLO progression *within* each department.

5. Numerical distance

Our analysis assumes that the numerical distance from for instance SOLO 2 to 3, is the same as between SOLO 3 and 4 etc, namely one numerical unit of difference, but does this mean that the "understanding step" between competencies listed as SOLO 2 and 3 is the same as the "step" between competencies listed as SOLO 3 and 4, etc.? Such an approach of quantifying qualitative data is however not uncommon to educational research. Oppenheim (1992) and Robson (2002) discuss quantitative research methods such as Likert scales that quantify degrees of agreement or disagreement using numbers, usually 1-5. Also, Oliver et al. (2004) have conducted a similar analysis using Bloom's Taxonomy on a handful of courses; they used Bloom's six levels to calculate averages using the numbers 1-6 as if the step distance were the same (and weighed the same). Not interpreted too dogmatically, such an approach will give relevant information about the approximate average level of competencies permitting us to roughly compare collections of courses. A way around this is to consider and compare the relative distributions of SOLO-levels; for individual courses (as in Figure 4 above) and for collections of courses (as in Figure 8 below). These two approaches will complement each other in this paper.

6. "Formulated outcomes" vs. "realized outcomes"

One might also raise the point that we focus on the *formulated* outcomes as seen in the ILOs even though it is not necessarily the same as the *formal*, *realized* (*operationalized*), or *learnt* outcomes (Bauersfeld, 1979, pp. 204-206; Goodlad, 1986, pp. 46-53). This is certainly true and it would also be very relevant to investigate the relationship between for instance the formulated curriculum, how it is taught, and what is actually learnt but this is not the scope of this paper. We have chosen to focus on the *formulated* ILOs since, owing to the new Danish grading scale, these have a strong impact on the grading since grades are to be given based on how well students meet the ILO. Furthermore owing to the constitutional effect of examination on learning, they also have an impact on the learning. Finally, in the event of students complaining about grades, it is legally the *formulated* outcomes that matter. Thus, teachers are forced to take the formulated outcomes very seriously.

Results and discussions

Below we exhibit the results of our analysis within each of the three focus areas of our research. But first we present an overview of each of the results of all departments at the two faculties. We calculated the SOLO-average (for each department) by averaging the results of all courses within that department. This resulted in the following table:

Department	AU	SDU	average	diff.
Science History & Education	4.0		4.0	
Computer Science	3.7	3.4	3.6	0.3
Biology	3.5	3.3	3.4	0.2
Molecular Biology	3.5	3.3	3.4	0.2
Chemistry	3.3	3.4	3.4	0.1
Physics	3.3	3.3	3.3	0.0
Geology	3.2		3.2	
Mathematics	3.1	2.8	3.0	0.2

Figure 6: "SOLO averages" by department and university.

We show all results using one decimal point only, as further precision is not warranted by the size of our data sets. Note that both averages and differences were calculated before rounding off to one decimal point, which is why some of the data appears to be off by ± 0.1 point (e.g., the 'difference' for Mathematics). It is worth noting that the Departments are not identically structured at the two universities; Computer Science, for instance, is a Department at AU while combined with Mathematics at SDU. This, however, does not affect our analysis as courses were tagged with identifiers allowing us to separate out the courses by subject. As for the progression analysis, we excluded the department of Science History and Education at AU since it offers only graduate courses, wherefore a discussion of progression from undergraduate to graduate level does not make sense. This is most likely the explanation for its high SOLO average at the top of the table along with the fact that it is the most "humanistic" department at the faculty of science, wherefore its course descriptions generally use many higher SOLO-levels (in fact, the two SOLO 5 competencies: "to discuss" and "to reflect" respectively account for 18% and 17% of all competencies).

Progression

1. Is there progression in competencies in the curricula from undergraduate level to graduate level?

For each of the departments that had both undergraduate and graduate programs, we calculated the SOLO-average for the undergraduate and graduate courses, respectively (see also Appendix D):

Uni.	Department	undergrad	graduate	Progression
AU	Computer Science	3.3	3.8	0.5
	Geology	2.9	3.3	0.4
	Molecular Biology	3.3	3.6	0.3
	Biology	3.3	3.5	0.2
	Physics	3.3	3.3	0.1
	Chemistry	3.4	3.3	-0.1
	Mathematics	3.2	2.9	-0.3
SDU	Molecular Biology	3.1	3.5	0.4
	Chemistry	3.3	3.6	0.2
	Physics	3.2	3.4	0.2
	Computer Science	3.3	3.4	0.1
	Biology	3.2	3.3	0.1
	Mathematics	2.8	2.9	0.1

Figure 7: SOLO-progression from undergraduate to graduate level (incl. difference; i.e. progression).

The ‘progression’ column consists of graduate SOLO-average minus undergraduate SOLO-average. Note again that the progression was calculated before the numbers were rounded off which is why some of the data appears to be off by ± 0.1 point (e.g., Physics at AU and Chemistry at SDU). The table is ordered by decreasing progression for both universities. In seven cases, we see a relatively clear progression from 0.2 to 0.5 (which is quite a lot on the SOLO scale). In five cases, we see little or no progression (within ±0.1 SOLO-levels), although predominantly positive. In only one case, we see a quite clear SOLO-regression; namely for Mathematics at AU. It is worth noting that Mathematics at SDU also shows close to no SOLO-progression.

Since we wondered about the presumable reverse SOLO-progression at the Department of Mathematics, AU, we presented our findings to the new and former study leader of Mathematics who believes that some of the reasons for both the low SOLO-average and presumable SOLO-regression is in the type of examination. At the graduate level almost all examinations are oral and they have aligned their ILOs to this examination type that was given by the Study Board. Oral examinations in mathematics generally have a lower SOLO-level (2-3) since they mainly consist of reproducing proofs from books “on the blackboard”. They also explained that for mathematics it is usually not until the Ph.D.-level that the students reach SOLO 5 and to some extent also SOLO 4. The main reason is that to be able to give a qualified critique of mathematics requires a counter proof or counter example as well as a large overview over mathematics which the students usually do not have before Ph.D. level. They also stated that much of their progression is in the content and the level of abstraction. This is not really “caught” by the SOLO taxonomy. In fact, the same SOLO verbs can be used for different contents; hence *progression in difficulty* is not always reflected by the *SOLO-progression* in verbs. Furthermore getting familiar with for instance epsilon-delta definitions is very difficult to most students even though in terms of SOLO-level, this would only be SOLO 2.

Educational Traditions and Nature of Subjects

2. Are there differences between the departments at the same Faculty of Science?

To get a picture of this we decided, in addition to the information from the figures above, to get an overview of the distribution of SOLO-competencies, which gave us the following figure:

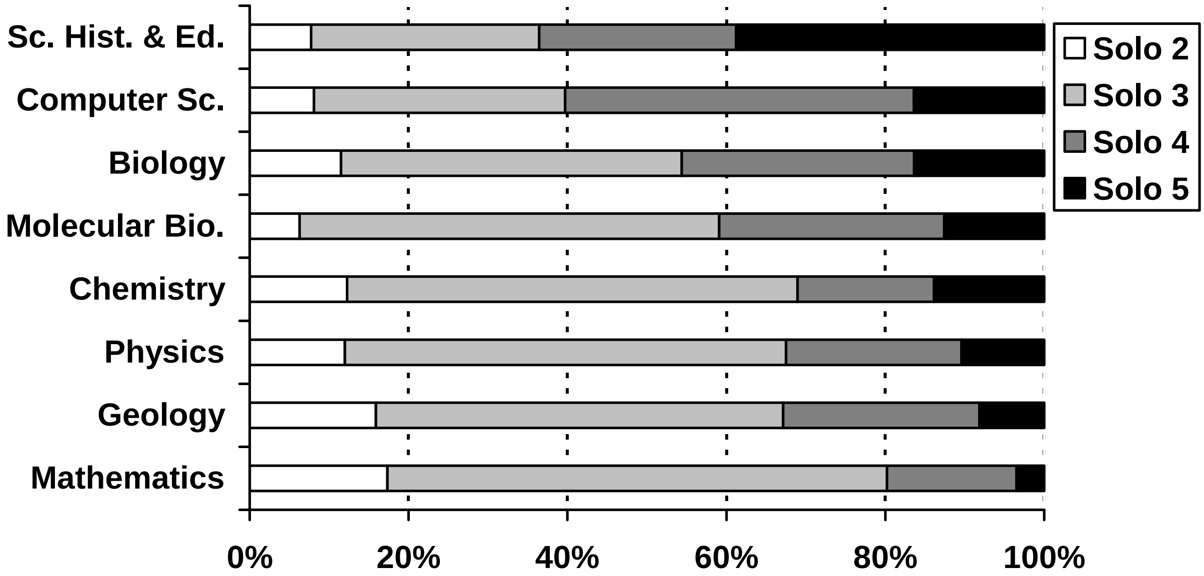
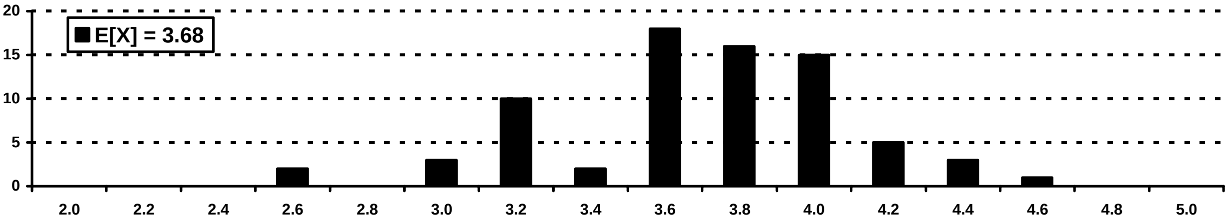


Figure 8: Distribution of competencies by SOLO-levels for the different departments at NAT/AU.

The figure reveals that Science of History and Education is indeed the subject with the most SOLO 5 competencies involved (35%); and, that Mathematics is clearly the subject with the least higher-level outcomes at stake. This is presumably because it takes longer in Mathematics to build up enough prerequisitional techniques and theories in order to act at the higher cognitive levels (e.g. ‘reflect’ on and ‘discuss’ mathematical theories). Madsen and Winsløw investigated this phenomenon by comparing Mathematics with Physical Geography at another Danish university. They concluded that Mathematics was often perceived as a more *vertical discipline* in which “extensive prerequisites are needed … because techniques and theories are built up in cumulative ways”, while Physical Geography as a more *horizontal discipline* where “different … [domains] live side by side, sometimes interacting, but not drawing on each other as strict prerequisites” (Madsen & Winsløw, 2008, p. 12). Finally, it is interesting to note that Computer Science seems to have a lot of SOLO 4 competencies involved; investigating a bit further reveals that the five competencies: ‘explain’, ‘analyze’, ‘implement’, ‘compare’, and ‘construct’ account for a total of 35% of all Computer Science competencies. To get further information we chose to get an even close look at the Department of Mathematics and the Department of Computer Science at AU. We investigated the distribution of courses according to their average SOLO-levels. In both cases, we plot the data as histograms with average SOLO on the x-axis as 0.2 point wide intervals and with the number of courses within each interval on the y-axis:



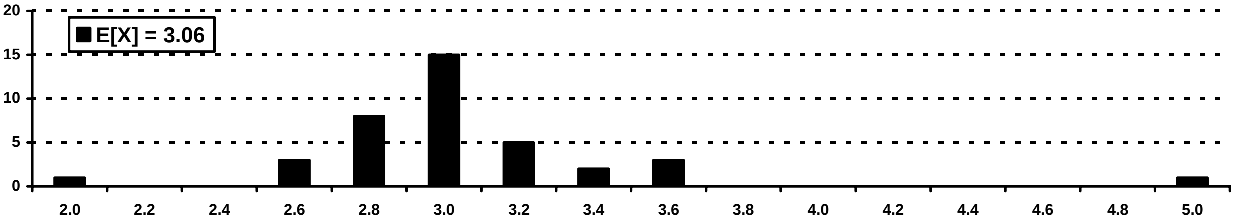


Figure 9: Distribution for two courses at AU: Computer Science (above) vs. Mathematics (below).

As can be seen the courses seems to follow a normal distribution with the mean values remarkably different for the two subjects; in fact, the Computer Science courses distribute as $\Phi(\mu = 3.68, \sigma = 0.39)$, while Mathematics as $\Phi(\mu = 3.06, \sigma = 0.24)$ when excluding the two isolated points at both ends. The sister departments at SDU exhibited similar normal distribution histograms.

Stability across universities

3. Are there differences between sister-departments at the two Faculties of Science?
Figure 6 reveals that the order of departments according to their average SOLO-levels is almost exactly the same for each of the three columns, when moving between universities. This lends to the stability of the analysis. Also, the two histograms of Figure 9 are has a very similar normally distributed structure when compiled for SDU. AU and SDU are two different universities. AU was a founded in 1928 although the Faculty of Science was not created until 1954. SDU is a newer university, founded 1966 as Odense University, but in 1998 it merged with other higher education institutions and centres to form SDU. We thus expected some differences among the sister-departments. However, it does appear that educational traditions and the nature of subjects are strong forces within science. One might argue that the implementation of the new curricula might have caused “convergence” for the two faculties. However, the point of the formulation of ILOs was to draw out and explicate the learning outcomes that were already there but tacit, between the lines, not to impose new ILOs.

Conclusion

In relation to progression, the use of the SOLO Taxonomy showed that competency progression in terms of SOLO does indeed exist, except for Mathematics, from undergraduate to graduate level. But what have we actually shown? There are two possible conclusions; *either:*

- The SOLO Taxonomy has “proved” that progression does indeed exist in the curricula (since we “believe” in the SOLO Taxonomy); *or*
- The SOLO Taxonomy has “been proven” to be a good tool for analyzing competence progression (since we “believe” in the existence of progression owing to capable university academic staff all of whom aimed at this and).

These could both be valid conclusions from our analysis, but not all at once. We focus on the latter since although we do believe that SOLO is an appropriate progression measure (see assumption 2 above), we have specifically investigated science curricula, but SOLO is *not* made with only *science* academic teaching in mind. Furthermore, progression is something that universities have always focused on. For Mathematics, however, given that we also believe in the existence of progression in mathematics programmes, SOLO does not seem to be as appropriate in describing and “catching” the mathematical progression (see also Brabrand & Dahl, 2008).

We have also shown that not all verbs have a fixed SOLO-level and that some are connected with the faculty in question. Hence some verbs are more ambiguous or fluid.

In relation to nature of subjects, one may also argue that what we in fact investigate more the "education tradition" within each department. However, we assume that this is not entirely distinct from the actual nature of the subject and we also believe, that in fact the subjects *are* different and that it is not only a question of educational traditions. This is also seen in the fact that there seems to be stability between sister-departments at the two universities. But to truly investigate this, we would need to also look at universities in other countries.

In any case, when students in the future ask their university teachers at NAT/AU and NAT/SDU "what's the use of this?" the implementation and use of the SOLO language might hopefully result in more clear explanations hereof and with fewer non-operational and ambiguous learning objectives such as 'understanding'.

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Appendix A: The Danish "7-Steps Grading Scale"

The new grading scale reflects the European Credit Transfer and Accumulation System (ECTS) (Dahl et al., 2009). Below is a translated list of the new Danish grades (numbers) and the ECTS grades (letters), respectively:

Grade value	English Description (…translated from Danish by the authors. Danish original text below)	ECTS equiv.
12	For an *excellent* performance which completely *meets* the course objectives, with no or only a few insignificant weaknesses. Karakteren 12 gives for den fremragende præstation, der demonstrerer udtømmende opfyldelse af fagets mål, med ingen eller få uvæsentlige mangler.	A
10	For a *very good* performance which *meets* the course objectives, with only minor weaknesses. Karakteren 10 gives for den fortrinlige præstation, der demonstrerer omfattende opfyldelse af fagets mål, med nogle mindre væsentlige mangler.	B
7	For a *good* performance which *meets* the course objectives but also displays some weaknesses. Karakteren 7 gives for den gode præstation, der demonstrerer opfyldelse af fagets mål, med en del mangler.	C
4	For a *fair* performance which adequately *meets* the course objectives but also displays several major weaknesses. Karakteren 4 gives for den jævne præstation, der demonstrerer en mindre grad af opfyldelse af fagets mål, med adskillige væsentlige mangler.	D

02	For a *sufficient* performance which barely *meets* the course objectives. Karakteren 02 gives for den tilstrækkelige præstation, der demonstrerer den minimalt acceptable grad af opfyldelse af fagets mål.	E
00	For an *insufficient* performance which does not *meet* the course objectives. Karakteren 00 gives for den utilstrækkelige præstation, der ikke demonstrerer en acceptabel grad af opfyldelse af fagets mål.	Fx
-3	For a performance which is *unacceptable* in all respects. Karakteren -3 gives for den helt uacceptable præstation.	F

Appendix B: Original references to Gall (1970)

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Appendix C: The entire data material

The data for the entire analysis is available online (in browseable XML format) here, in Danish:

Online location (URL):	Data	Description
`www.itu.dk/people/brabrand/solo.xml`	SOLO data	SOLO attribution of all competencies occurring in both data sets (cf. below).
`www.itu.dk/people/brabrand/data-au.xml`	AU data	All competencies for all ILOs for all courses for all departments at AU.
`www.itu.dk/people/brabrand/data-sdu.xml`	SDU data	All competencies for all ILOs for all courses for all departments at SDU.

Appendix D: Size of data set

The figure shows the number of undergraduate courses plus the number of graduate courses in our data set at both universities. The final data set consisted of a total of 632 courses:

Department	AU	SDU	TOTAL
Science History & Education	26		26
Computer Science	16+59	18+09	119
Molecular Biology	26+31	25+12	94
Biology	16+56	23+19	114
Chemistry	29+19	19+13	80
Physics	26+38	07+19	90
Geology	12+44		66
Mathematics	18+22	22+08	70
TOTAL	438	194	632

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[1] Full name: Bettina Dahl Søndergaard (Soendergaard).

[2] The authors are listed in alphabetical order. They have contributed differently, but equally, to this paper.

[3] 'Academic staff' denotes all Assistant, Associate and Full professors.